Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Metals Technology Laboratories

Laboratoires de la technologie des métaux

Canada

METALS TECHNOLOGY LABORATORIES

STRESS CHARACTERIZATION IN PLATE HY80 BY X-RAY DIFFRACTION

E.J.-C. COUSINEAU AND P. FRYZUK

MTL 89-35(TR)

This document is an unedited internal report prepared primarily for publication and internal reporting purposes. It does not necessarily represent the final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire préparé principalement pour la publication et la distribution internes. Il ne représente pas nécessairement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

MICROMEDIA

13 pp

CANMET

90-01333/

METALS TECHNOLOGY LABORATORIES
REPORT: MTL 89-35(TR)

STRESS CHARACTERIZATION IN PLATE HY80 BY X-RAY DIFFRACTION

by

E.J.-C. Cousineau and P. Fryzuk

ABSTRACT

An HY-80 plate submitted to four-point bending has been analysed with the CANMET/PROTO stress diffractometer. The plate was investigated in the as-received condition followed by our conventional surface preparation. Data collected by the hole drilling method are also included for comparison. The plate was also examined for preferred orientation using the energy dispersive technique. The importance of a good surface preparation is clearly demonstrated if valid results are to be obtained.

LABORATOIRES DE LA TECHNOLOGIE DES MÉTAUX
RAPPORT: MTL 89-35(TR)

CARACTÉRISATION DES CONTRAINTES DANS UNE PLAQUE D'ACIER HY-80 PAR DIFFRACTION DE RAYONS X

par

E.J.-C. Cousineau et P. Fryzuk

RÉSUMÉ

Une plaque d'acier HY-80 qui a été soumise à des essais de fléchissement en quatre points, fut examinée avec le diffractomètre CANMET/PROTO. Les contraintes résiduelles furent déterminées sur la plaque telle qui livrée et de même après que la surface eut reçu la préparation usuelle pour ces essais. Les données recueillies par la méthode de perçage de trou sont jointes pour fin de comparaison. La texture de la plaque à été déterminée par dispersion d'énergie. Il est clairement démontré qu'une préparation adéquate de la surface est primordiale pour l'obtention de bon résultat.

INTRODUCTION

Several techniques may be used to evaluate the stress in various materials. In this report, the CANMET Proto Stress Analyser, which applies the X-ray diffraction method, was used. This technique is well documented in many papers (1-3) and will not be discussed here. The ferritic plate HY80, which was submitted to four-point bending prior to its examination by X-ray diffraction, was supplied by Defense Research Establishment Atlantic (DREA). The plate had been subjected to other non-destructive investigations before its arrival at MTL.

TECHNICAL DATA

The plate (ASTM A543/A543M; HY80) was fabricated from a Ni-Cr-Mo alloy steel intended for fabrication of welded pressure vessels. Physical dimensions are given in Fig. 1. Prior to bending, the plate was heated to an austenizing temperature of 904°C and held for 80 min. It was water quenched, and then tempered at 710°C for 70 min following the procedure for heat treatment of QT28 steel. It was also pulled beyond yield along the longitudinal direction prior to bending.

PROCEDURE

The residual stress measurements were carried out on the convex side in the as-received condition which was a flat, smooth and shiny surface at 165 mm from the left side of the plate and 52 mm from the top, as indicated in Fig. 1. The plate was then turned over and similar data were collected on the concave side at a location 167 mm from the side and 42 mm from the top. This area, point D on Fig. 1, had been prepared by electropolishing by Proto Mfg using a 90% ethanol-10% perchloric solution.

Two new areas were selected, one on the convex side which was only chemically polished using Kawamura's solution consisting of 8% HF, 60% H_2O_2 and 32% H_2O. The total amount of material removed was approximately 0.15 mm over a diameter of 30 mm. The concave side was ground lightly, down to 600 grit, with a Transpol disc grinder in order to remove the oxide scale from the surface, then chemically polished dissolving away about 0.10 mm to take off the deformed layer due to grinding. Following this surface preparation, the stresses were measured at the 167 mm location for the convex side and 190 mm for the concave (see Fig. 1).

The hole drilling technique was then used to estimate the stress in the material. The holes were drilled in the polished area for both the convex and the concave surfaces. Those results will be reported separately (5). Following this test, the area under investigation on the convex side was chemically polished removing another 0.04 mm, then stresses were measured at a location of

160 mm from the left side of the plate. This location is at a distance from the edge of the hole that exceeds the minimum which is 1.5 times the diameter of the hole.

The reference frame was chosen such that the 0° orientation of the instrument corresponds to the longitudinal direction of the specimen, 90° being across the plate. The CANMET diffractometer is capable of both single exposure technique (SET) and multiple exposure technique (MET) (2), but in the present case only the SET facility of the instrument was used. For each one of the five locations mentioned above, the procedure was identical. First, the calibration of the detectors, to a known Bragg angle, was carried out; this also created a file on disk, which is required later by the main software. A stress-free standard was analysed to ensure that the diffractometer was properly set. Finally, three independent sets of diffraction profiles were collected from which the residual stress was calculated. This full procedure was repeated for the 45° and the 90° orientation of the specimen.

A strip 15 mm wide was cut at the right-hand side of the plate; from this, a 25 mm long specimen was ground and chemically polished using Kawamura's solution mentioned above. Data were collected by the energy dispersive technique (4) for the creation of inverse pole figures which revealed the texture of the plate.

RESULTS

The residual stresses measured on the plate in the so-called as-received condition are listed in Table 1. The convex surface exhibited compressive stresses varying from -261 MPa in the longitudinal direction to -224 MPa in the direction across the plate. This variation is not significant, since each figure is within one standard deviation. The concave surface revealed compressive residual stresses of the same magnitude in the 0° and 45° orientation, -255 MPa and -223 MPa, respectively, while being only -86 MPa at the 90° orientation. These figures do not correspond to those obtained by other techniques nor do they fit the expected result for this type of bending experiment which predicts a compressive residual stress for the outside portion of the convex surface and a tensile residual stress for the outside portion of the concave surface (6).

At this point, an investigation was carried out to see if this misbehaviour of the plate could be influenced by any texture present in the plate. The standard unit triangle representation for ferritic material is shown in Fig. 2. As is demonstrated by the various σ, the orientation distribution ratio, no evidence of texture was observed since they all fluctuated around 1.0, indicating a random distribution of crystallites in the material.

Since there was no evidence of surface preparation by chemical or electro-polishing on the convex surface, we used our standard technique for surface preparation of a specimen and the areas at 165 mm for the convex side and 190 mm for the concave (see Fig. 1) were prepared. The

stresses measured at those locations are listed in Table 2. The longitudinal direction of the convex surface still exhibited a compressive stress, but of lower magnitude at -153 MPa. In the 45° direction, it was still compressive but much lower at -34 MPa.

Examination of the results obtained on the concave surface allowed us to verify that indeed we had the expected reversal from compression to tension and vice versa. The longitudinal direction showed 156 MPa, the 45° orientation indicated 44 MPa, however, the magnitude of the residual stress measured across the plate was much different.

In order to ascertain that these measurements were really taken below the deformation layer introduced by the machining of the plate and truly represent the stress distribution of the specimen due to the four-point bending test, additional material was removed by chemical polishing. It was hoped that this new surface would resolve the ambiguity in the data measured in the transverse direction. The results are presented in Table 3. As expected, the longitudinal direction still exhibited compressive stress but slightly less than the previous value at -130 MPa, as the removal brought the surface under investigation closer to the center of the specimen. The 45° orientation remained at a similar value, but the transverse direction dropped drastically to 47 MPa. Comparing this residual stress with the previous value of 107 MPa would imply a very large stress gradient in the plate. This large discrepancy and the fact that this newly measured residual stress is closer in magnitude to the value of the concave surface and to the value obtained by hole drilling method suggests that the first figure of 107 MPa could be attributed to local variation in the specimen.

After the first series of measurements was carried out, the presence of a cold-worked layer was suspected. Careful examination of the X-ray diffraction profiles should confirm this hypothesis since it is well known that cold work will increase the line broadening significantly. Several ways may be used to evaluate this broadening. The integral breadth, which is defined as the width of a rectangle whose area and height will correspond to the integrated intensity and diffraction peak height respectively. Since this was not present in the software at the time of the experiment, a much simpler technique, the full width at half maximum (FWHM), which is simply the width of the diffraction peak at 50% intensity after elimination of the background, polarization correction and removal of the α_2 component of the K doublets, was used. This value can be measured directly from the graphical representation of the diffraction profile. Figures 3, 4 and 5 show the X-ray diffraction profile which could be used to obtain the FWHM for the HY80 plate in the as-received condition, after surface preparation and following the second chemical etch, respectively, for both detector #1 and detector #2. As can be seen, the FWHM decreases considerably from 21 mm to 14 mm from Fig. 3 to Fig. 4, as measured on peak #1, while it is very similar at 13 mm in Fig. 5.

CONCLUSION

The CANMET portable stress diffractometer was used successfully to evaluate the residual stress in the HY80 steel plate which had been submitted to four-point bending. The X-ray data agreed very well with the value obtained by a standard hole drilling method and the theoretical prediction for this type of test. However, this experiment demonstrated very clearly the importance of good surface preparation prior to taking any measurements. It would appear that a chemical etch removing about 0.1 mm will yield an adequate surface, free of any cold-worked layer. Another good feature which could be added to the existing software of the stress diffractometer is the calculation of the integral breadth with a warning to the user when it exceeds a fixed or premeasured value compared with a standard.

REFERENCES

1. Mitchell, C.M. "The CANMET portable stress diffractometer"; Proc. Int. Conf. on Pipelines; Edmonton, Alberta; Government of Canada Publishing Centre, Ottawa; 1983.

2. Holt, R.A. "A compressive approach to in-situ stress measurement "; Advances in X-ray Analysis 29:29-35; 1986.

3. Holt, R.A., Brauss, M. and Boag, T. "In-situ stress measurement with the CANMET portable X-ray stress diffractometer"; Nondestructive Characterization of Materials II, Plenum Publishing Corp. pp 615-623; 1987.

4. Mitchell, C.M. and Fegredo, D.M. Canadian Metallurgical Quarterly 14:3; 1975.

5. Roy, G. and Kiff, D "Residual stress determination in HY80 plate by the hole drilling method"; Draft Report; 1989.

6. Cullity, B.D. "Elements of X-ray diffraction"; Addison-Wesley; USA; 1978.

Table 1. Stress measured on the HY80 plate in the as-received condition.

	Stress (MPa)					
Exposure	Convex surface			Concave surface		
No.	0°	45°	90°	0°	45°	90°
1	-238	-206	-233	-273	-229	-79
2	-286	-248	-214	-240	-236	-91
3	-260	-229	-225	-252	-205	-88
4	--	--	--	--	--	--
Mean	-261	-228	-224	-255	-223	-86
S	24	21	10	17	16	6

Table 2. Stress measured on the HY80 plate after surface preparation.

	Stress (MPa)					
Exposure	Convex surface			Concave surface		
No.	0°	45°	90°	0°	45°	90°
1	-152	-46	111	159	49	-24
2	-158	-26	108	152	53	-10
3	-139	-29	112	157	30	-30
4	-163	--	98	--	--	--
Mean	-153	-34	107	156	44	-21
S	10	11	6	4	12	10
Hole drilling data*	-130	-48	35	150	48	-53

* See Draft Report (reference 5) for more details.

Table 3. Stress measured on the HY80 plate after the second chemical polishing.

	Stress (MPa)					
Exposure	Convex surface			Concave surface*		
No.	0°	45°	90°	0°	45°	90°
1	-127	-44	45	--	--	--
2	-122	-31	53	--	--	--
3	-140	-32	41	--	--	--
Mean	-130	-36	46	--	--	--
S	9	7	6	--	--	--

* Time constraint prevents measurement of this surface.

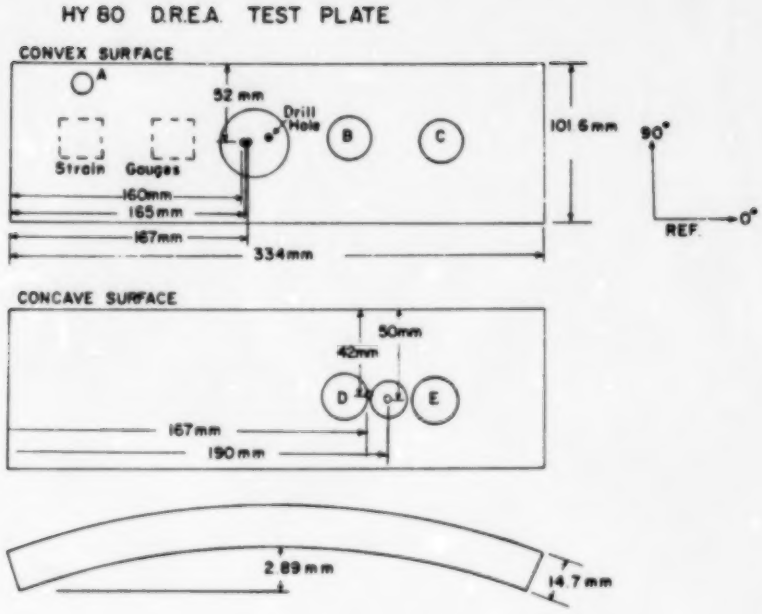

Fig. 1. Location of X-ray diffraction measurements. (neg 19646)

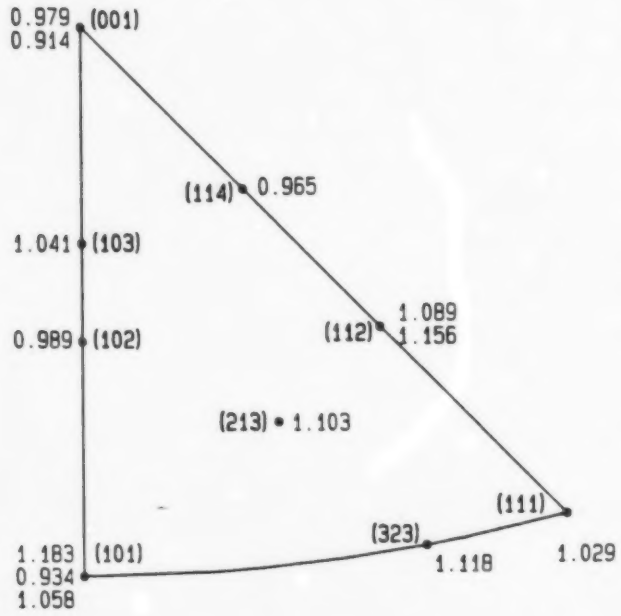

Fig. 2. Inverse pole figure for plate HY80. (neg 19647)

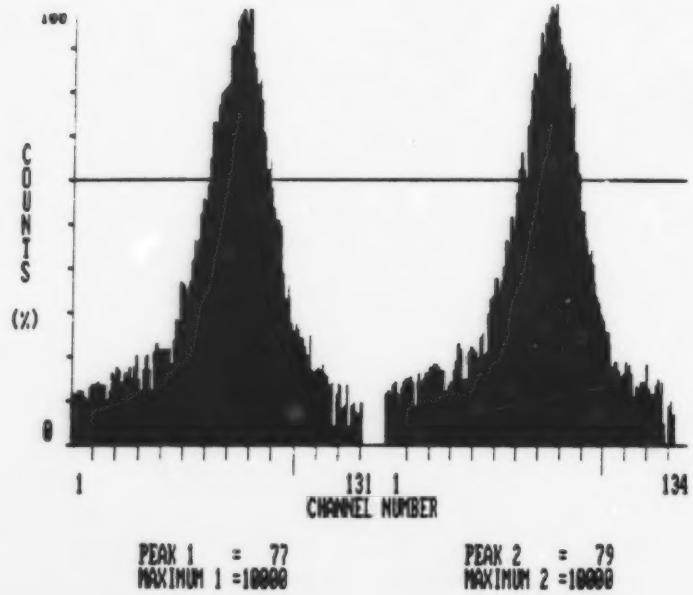

Fig. 3. X-ray diffraction profile of the surface of plate HY80 as received. (neg 19645)

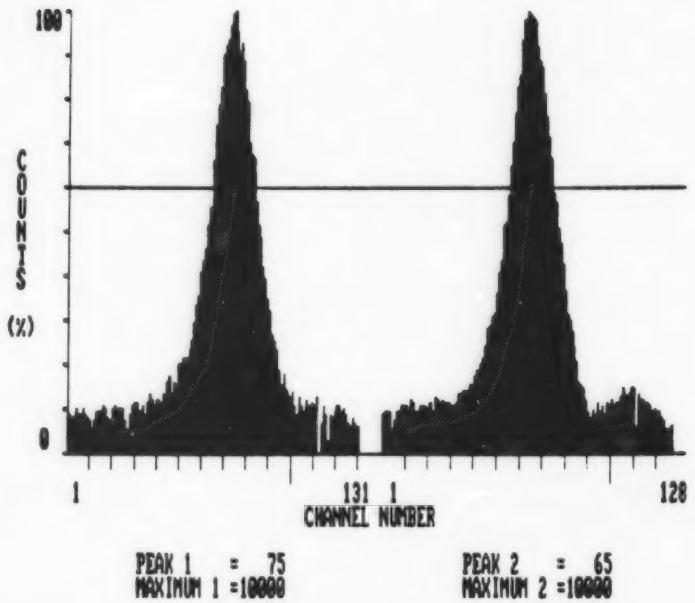

Fig. 4. X-ray diffraction profile of plate HY80 after surface preparation. (neg 19644)

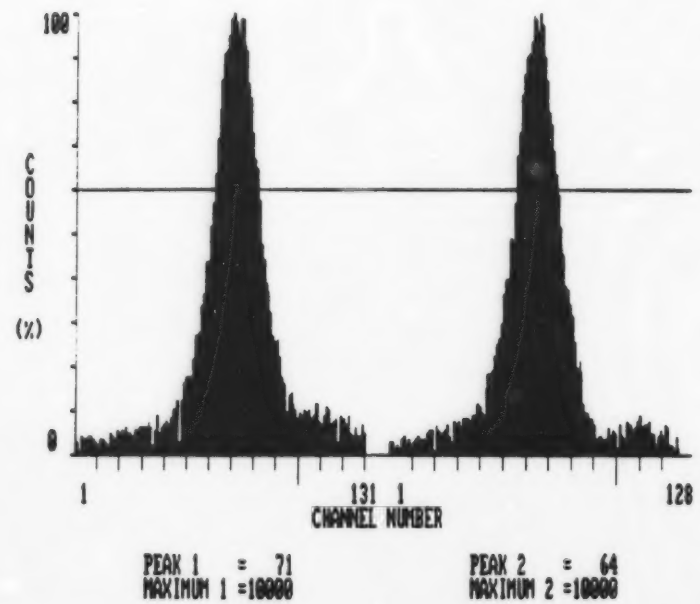

Fig. 5. X-ray diffraction profile of plate HY80 after second chemical polishing. (neg 19643)